EXHIBIT G

Exponent®

Thermal Sciences

Shamsher
v.
Omega Flex

Exponent®

Shamsher
v.
Omega Flex

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Contents

	Page
Executive Summary	**iii**
Background of the Incident	**1**
TracPipe Background	**5**
Safety of TracPipe	5
Lightning and TracPipe	6
Direct bonding of TracPipe	6
Analysis by Dr. Eagar regarding bonding	7
Codes and Industry Standards	8
Design Guide and Installation Instructions	9
TracPipe Testing Performed by Exponent	**11**
TracPipe and household electrical systems	11
Ignition of gas escaping from perforated TracPipe	12
Analysis of the TracPipe holes	**15**
Origin and Cause Analysis	**18**
Family room fire	18
Bedroom fire	20
Indirect lightning strike	21
Grounding and bonding	21
Limitations	**22**
Appendix A – Material Reviewed	**23**
Appendix B – Curriculum Vitae	

Executive Summary

Exponent was retained by Campbell Campbell Edwards & Conroy, PC to investigate a fire that occurred at the Shamsher residence, located at 13311 L'Enfant Drive, Fort Washington, Maryland, during the evening hours of July 23, 2009. The residence was supplied with natural gas, which was distributed throughout the residence through TracPipe, a corrugated stainless steel tubing (CSST) product manufactured by Omega Flex. A lightning storm passed through the area of the residence on the evening of the fire.

Materials reviewed

Exponent reviewed photographs that were taken of the scene of the fire on July 27, 2009 by Mr. Aaron Redsicker and photographs taken of the scene on August 27, 2009 by Mr. David Smith. Exponent also reviewed the reports authored by Mr. Aaron Redsicker, Mr. Mark Goodson, Mr. Ken McLauchlan and Dr. Tom Eagar. A full list of the material reviewed in this matter is provided in Appendix A.

Inspections

An inspection of electrical wires and duct sections that were removed from the residence was performed on February 6, 2012. A microscopic inspection of the TracPipe using a scanning electron microscope (SEM) was performed on January 30, 2012.

Testing

Exponent tested TracPipe in order to determine whether electrical arcing with household branch circuit wiring can produce holes in TracPipe during a fire. Exponent also tested the ignitability of natural gas leaking from a perforation in TracPipe.

My curriculum vitae, including a list of publications, are provided in Appendix B.

Findings and opinions

Based on my education, background, training, experience, testing, and analysis in this matter and my review of the relevant materials, I offer the following opinions to a reasonable degree of engineering and scientific certainty. If additional information becomes available, I reserve the right to modify or amend these findings:

1. TracPipe is a safe and effective product for distributing fuel gas throughout a residence if it is installed and maintained properly according to the manufacturer's instructions that are provided in the Omega Flex TracPipe Flexible Gas Piping Design Guide and Installation Instructions (D&I Guide).

2. A TracPipe gas distribution system in a home is less prone to leaks than black iron pipe gas distribution systems. This is in part because black iron pipe requires more fittings than TracPipe.

3. TracPipe is more flexible than black iron pipe and therefore is less susceptible to damage than black iron pipe during acts of nature such as earthquakes, tornados, and hurricanes that may cause structural damage to a residence.

4. Lightning can enter a home due to direct or indirect lightning strikes, often through metallic roof penetrations, the household electrical system, or utilities.

5. Direct bonding of TracPipe, as prescribed by the Omega Flex D&I Guide is necessary to significantly reduce the likelihood of arcing between TracPipe and another conductor such as a metal duct, water pipe, or branch circuit wiring in an indirect lightning strike.

6. The requirements for direct bonding of TracPipe to a grounding electrode are clearly described in the Omega Flex D&I Guide. If an installer is not sure of the requirements, the installer should contact the manufacturer for clarification prior to putting the gas system into service.

7. The TracPipe system at the Shamsher residence was not directly bonded to a grounding electrode, and thus was not installed in accordance with the manufacturer's instructions.

8. The 2006 National Fuel Gas Code (NFPA 54) requires that CSST be installed in accordance with the manufacturer's instructions. The installer of the TracPipe in the Shamsher home failed to install the product in accordance with the TracPipe D&I Guide and thus did not follow the requirements of NFPA 54.

9. Electrical arcs are rapid releases of electrical energy, which are capable of igniting combustible materials. Electrical arcs of sufficient magnitude can also cause a hole in TracPipe by localized melting of the stainless steel.

10. A hole can form in the stainless steel wall of TracPipe by electrical arcing with a branch circuit wire energized by household electricity in the presence of a pre-existing fire. This means that holes with evidence of melting found in TracPipe during a fire investigation may have been formed by arcing after the fire started.

11. The source of electrical energy for an arc that melts a hole in TracPipe cannot be determined by microscopic examination of the hole alone.

12. Natural gas leaking from a hole in a TracPipe line at household line pressures cannot be ignited by an ignition source located at the hole because the gas velocity is too high for combustion to be sustained. Molten metal near the hole is not a viable ignition source due to the high speed of the gas flow relative to the molten metal and the small size of the metal droplets.

13. There were two independent fires at the Shamsher residence. One was above the basement family room between the ceiling and the first floor subfloor (the family room fire). The other was above the ceiling of the spare basement bedroom (the bedroom fire).

14. The family room fire was caused by one or more electrical arcs due to lightning involving branch circuit wires in the area of origin. An initial arc may have allowed additional follow-on current to flow from an energized branch circuit wire. The electrical event likely ignited combustible materials, such as dust, wood, insulation, or paper.

15. The hole in the TracPipe found in the vicinity of the family room fire was caused either by electrical arcing due to lightning between a branch circuit wire and the supply TracPipe line, or by electrical arcing between a branch circuit wire and the TracPipe in the presence of an existing fire. The escaping natural gas was then ignited by an existing fire at least several inches from the hole.

16. The bedroom fire caused very little damage. It was not discovered by the fire department but instead self-extinguished. The bedroom fire was caused by electrical arcing due to lightning between a metal duct and the TracPipe supply line. The arc melted a hole in the TracPipe, and combustible material in the vicinity, such as wood shavings or dust, were ignited during this electrical event causing a small fire. Leaking gas from the TracPipe was then ignited at least several inches away from the hole by this small fire.

17. The cause of the fires at the Shamsher residence was lightning, which is a natural fire cause.

18. The holes in the TracPipe at the Shamsher residence would not have formed if the TracPipe system was directly bonded to a grounding electrode as per the manufacturer's instructions.

Background of the Incident

The Shamsher residence, located at 13311 L'Enfant Drive, Fort Washington, Maryland was constructed in 2006. The permit for natural gas was issued on May 22, 2006, the final plumbing and gasfitting inspection was performed on November 17, 2006.[1] The residence has two stories and a finished basement that was used as a living space. A photograph of the residence after the fire is shown below in Figure 1. The majority of the fire damage was confined to the basement. The basement had a concrete floor covered with tile or carpeting and concrete walls. Wood framing and drywall was installed against the concrete walls, with insulation between the wood studs. The first floor was supported by wood I-joists. The basement ceiling was finished with drywall.

Figure 1. Photograph of the Shamsher residence, taken a few days after the fire.[2]

Electrical service entered the residence through the north (front) side of the residence. The main electrical panel was grounded through a grounding conductor connected to a buried grounding rod. The water supply system was also bonded to the electrical system ground.

[1] December 9, 2011 report by Mr. Redsicker.

[2] From set of photographs taken by Mr. Redsicker on July 27, 2009.

Natural gas service entered the residence at the west side. Natural gas was distributed throughout the residence by TracPipe, a brand of corrugated stainless steel tubing (CSST) manufactured by Omega Flex. A ¾" TracPipe supply line ran from the point of gas service entrance to the residence to a regulator in the basement which reduced the gas pressure from 2 psig to 7 inches water column (w.c.), which is about 0.25 psig. A manifold was connected to the regulator which distributed natural gas to six separate ½" TracPipe lines. These lines fed a hot water heater, a basement furnace, a second basement furnace, an attic furnace, a fireplace, and an oven. The gas distribution system was not bonded to a grounding electrode as required by the TracPipe Flexible Gas Piping Design Guide and Installation Instructions (D&I Guide).

On the night of July 23, 2009, a lightning storm passed near the Shamsher residence. There were numerous lightning strikes throughout the area. The closest lightning strikes (within 0.2 miles) occurred between about 10:30 PM and 10:36 PM.[3]

Mr. Shamsher first observed smoke coming from the electrical outlets above the kitchen counter. This prompted him to exit the home and dial 911. The fire department incident report stated that the fire was reported at 10:53 PM. The fire department arrived at 11:03 PM and extinguished the fire.[4]

The fire that was identified and extinguished by the fire department was in the basement family room, below the kitchen, between the basement ceiling drywall and 1st floor sub-floor, near the south wall (the family room fire). A hole was found in the TracPipe oven line in the vicinity of the family room fire.

There was also a smaller fire that was not identified by the fire department or by the initial scene inspection performed by Mr. Redsicker. This fire was confined to an area above the ceiling of the basement bedroom near the north wall (the bedroom fire) and was discovered by contractors who were removing drywall in the basement bedroom ceiling. This fire apparently self-extinguished and caused only minimal damage. A hole was found in the TracPipe supply line in the vicinity of the bedroom fire. Photographs of the damage caused by the family room fire and the bedroom fire are shown in Figure 2 and Figure 3. A schematic drawing of the basement, approximate fire locations, and TracPipe lines is shown in Figure 4.

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[3] Vaisala STRIKEnet report.

[4] Prince George's County Fire/EMS Department Incident Report 2009-2040426.

Figure 2. Photograph of the fire damage to the ceiling above the basement family room.[5]

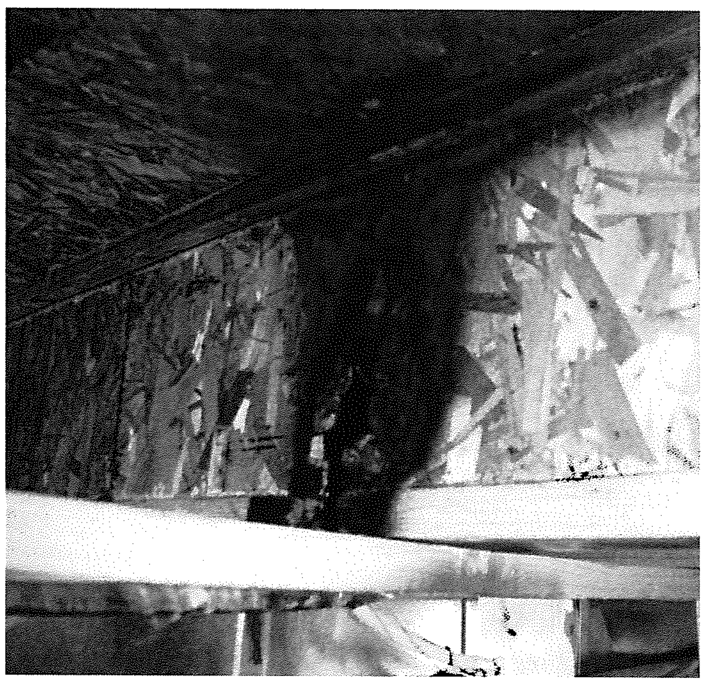

Figure 3. Photograph of the fire damage to the I-joist above the basement bedroom ceiling.[6]

5 From set of photographs taken by Mr. Redsicker on July 27, 2009.

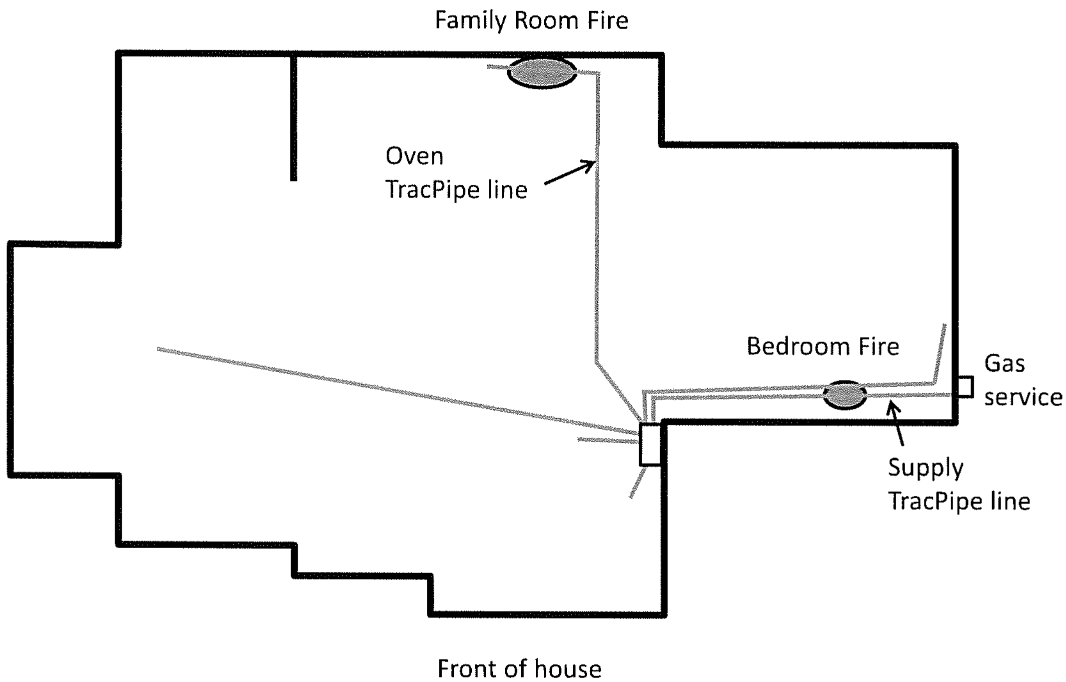

Figure 4. Schematic drawing of the basement of the Shamsher residence showing the TracPipe lines and approximate locations of fire damage.[7]

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6 From set of photographs taken by Mr. Smith on August 27, 2009.

7 Based on the diagram included in the September 25, 2009 report by Mr. Smith.

TracPipe Background

Corrugated Stainless Steel Tubing such as TracPipe is commonly used in residences to distribute fuel gas (either natural gas or propane) throughout the structure. TracPipe is often used either in conjunction with or in place of traditional black iron pipe. Black iron pipe is carbon steel pipe with a black galvanic coating on its exterior to protect it from corrosion. Black iron pipe, unlike TracPipe, must be installed in straight rigid lengths connected by multiple threaded fittings.

Safety of TracPipe

The installation of a black iron pipe gas system throughout a structure often requires the use of many threaded fittings to change directions as the pipe is routed through walls, ceilings, and crawlspaces. Since TracPipe is flexible, it only requires fittings at junctions and at connections to appliances. Thus the installation of TracPipe requires many fewer fittings than the installation of black iron pipe for a similar household configuration. Therefore the installation of a TracPipe system is more efficient and less expensive than a black iron pipe system. More importantly, this means that TracPipe is less prone to leaks. Gas leaks can occur at a fitting due to the fitting not being properly tightened, and are a common safety hazard in homes with gas service. TracPipe reduces the risk of gas leaks and is safer than black iron pipe in this regard.

TracPipe also provides additional safety as compared to black iron pipe in resisting damage due to acts of nature, such as earthquakes, tornadoes, and hurricanes. If an earthquake causes a shift in the house foundation or structure, this may cause relative movement of two ends of a gas line. If that gas line is TracPipe, the inherent flexibility of TracPipe can accommodate that movement without damage. If however, the gas line is black iron pipe, the pipe may break due to the stresses induced by the movement of the structure.[8] TracPipe is similarly more resistant to damage due to other acts of nature such as tornados and hurricanes that may cause movement of the structure.

TracPipe is UL listed and thus has been independently tested and found to be suitable for the distribution of fuel gas within a structure in accordance with ANSI LC-1/CSA 6.26 Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing (CSST). In addition, TracPipe is intended only to be installed by a qualified installer. The TracPipe D&I Guide states: "TracPipe gas piping material must only be installed by a qualified person who has been trained or otherwise qualified through the TracPipe Gas Piping Installation Program. Any installer must also meet qualifications in accordance with state and/or local requirements as established by the administrative authority which enforces the plumbing or mechanical code where the gas piping is installed."[9]

8 *Testing to Compare the Seismic Response of TracPipe Flexible Gas Piping (CSST) with Black Steel Piping Systems Under Simulated EarthQuake Induced Motions.* Report to Omega Flex 11/11/1998

9 TracPipe Flexible Gas Tubing Design Guide and Installation Instructions, December 2005, Page 3.

Lightning and TracPipe

Lightning is an extremely energetic physical event which is responsible for causing about 4,400 home fires in the United States each year.[10] Lightning can enter a residence through multiple routes. Lightning may directly strike the side or roof of a residence. Metallic roof penetrations such as flue pipes are especially common lightning strike locations, as they often represent the highest and most conductive path to ground within a structure. Lightning that directly strikes a utility, such as an overhead power line, may travel through the power lines into a residence. Lightning that does not directly strike a residence or utility may also enter a residence indirectly, through the ground. A lightning strike to a tree or directly to the ground can raise the electric potential of the ground nearby causing electrical energy to flow into a residence through the water pipes or through a grounding rod. Once electrical energy enters a home it will flow through any and all conductive paths, including electrical wiring, communications wiring (such as cable service), metal ducts and vents, water piping, and gas piping.

Electrical current flows preferentially through paths of lower impedance. If two nearby conductors are not electrically connected through a sufficiently low impedance, a voltage (or electrical potential difference) can exist between these two conductors. If the voltage is high enough, an electrical arc can form between the conductors. The voltage threshold necessary to cause an arc depends on the distance between the conductors and the insulating material between them. The plastic coating on branch circuit wires and on TracPipe is designed to be a good electrical insulator; air is a comparatively poorer insulator.

An electrical arc is an extremely rapid discharge of electrical energy that generates both light and heat while transferring electric charge. An electrical arc is capable of melting copper wires, and igniting combustible materials such as wood, paper, or dust. A sufficiently energetic arc involving TracPipe can cause localized melting of the stainless steel, sometimes forming a hole in the TracPipe.

If a residence is subject to a direct lightning strike, the lightning is capable of causing significant damage to the electrical, plumbing, ventilation systems, and appliances of the home as well as to combustible materials such as wood studs, joists and roof shingles, often resulting in a fire. It is possible to protect against direct lightning strikes using a Lightning Protection System (NFPA 780), but due to the rarity of lightning strikes to homes, the authorities that have jurisdiction over the construction of safe homes throughout the U.S. do not require the use of Lightning Protection Systems in homes. For this reason, the Lightning Protection System is voluntary.

Direct bonding of TracPipe

In order to significantly reduce the likelihood of perforation of TracPipe due to lightning induced arcing from an indirect lightning strike, it is necessary to follow the manufacturer's instructions and bond the TracPipe directly to the household grounding electrode, following the principal of equipotential bonding. This requires the use of a large gauge wire between the

[10] Evarts, Ben. *Lightning Fires and Lightning Strike.* National Fire Protection Association, Fire Analysis and Research Division. December 2010.

TracPipe system and the electrical system ground such that there is very low electrical impedance between the TracPipe and the electrical system ground.

During the electrical transients caused by lightning strikes, the voltage between TracPipe and other grounded conductors, such as electrical wires will generally be higher when the electrical impedance between them is higher. A higher voltage increases the possibility of arcing. Therefore reducing the electrical impedance to ground (through direct bonding) reduces the likelihood of an arc.

If TracPipe is connected to an appliance (such as a furnace or boiler) and that appliance has an electrical connection to ground (through grounded branch circuit wiring) the TracPipe will also have an electrical connection to ground. However, the impedance of the comparatively long, thin wire of the appliance ground connection (such as a 14 AWG branch circuit grounding wire) is much higher than of a short and thick (6 AWG) bonding wire connected directly to a grounding electrode. Therefore, grounding through an appliance is much less capable of preventing a high voltage and an arc between TracPipe and another household conductor which may be energized by a nearby lightning strike. Exponent is not aware of any perforations to TracPipe by indirect lightning strikes where the TracPipe system was properly bonded following the manufacturer's instructions.

Analysis by Dr. Eagar regarding bonding

Dr. Eagar states in his report that CSST would need to be bonded every 10 feet to prevent lightning induced arcing. His calculation is based on an assumption of a current of 100 kA flowing through CSST.[11] This is an unrealistically high figure, even for a direct lightning strike. Less than 1% of all lightning strikes in the United States have peak currents that exceed 100 kA.[12] For an indirect lightning strike, only a fraction of the strike current will enter the residence. Furthermore even if the current entering the residence is 100 kA, this does not mean that the full 100 kA current will flow through the CSST, as lightning will take all possible paths to ground including electrical wiring, communications wiring, metal ducts and vents, water piping, and gas piping.[13]

Additionally, Dr. Eagar's own analysis demonstrates that it was impossible for the TracPipe in the Shamsher residence to have been exposed to even 10 kA of current. In his report, Dr. Eagar explains that if CSST were exposed to 10 kA from a lightning strike, it would cause melting at the connections due to localized resistance effects.[14] There is no evidence of such melting in the Shamsher home. Therefore, based upon Dr. Eagar's analysis alone, we can conclude that the TracPipe in this incident carried less than 10kA.

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[11] December 12, 2011 report by Dr. Eagar, page 5, paragraph 6.

[12] Chowduri et.al. Parameters of Lightning Strokes: A Review. *IEEE Transactions on Power Delivery*. Vol 20, No. 1. January 2005. Furthermore, the Vaisala STRIKEnet report for the area near the Shamsher residence on the evening of the fire shows no strikes with a peak current above 52 kA within a 2 mile radius. Most of the strikes are around 10 to 20 kA.

[13] Similarly, Dr. Eagar's estimate of the time derivative of the current to be 100 kA/µs both overstates the typical maximum value for a lightning strike as a whole, and fails to account for the fact that lightning takes many paths to ground and does not flow only through a single run of CSST.

[14] December 12, 2011 report by Dr. Eagar, page 3, paragraph 2

Codes and Industry Standards

The installation of Omega Flex's TracPipe product is governed by the appropriate Design Guide & Installation Instructions (provided by Omega Flex), and the relevant codes and standards. This installation occurred after the initial gas permit was issued on May 22, 2006 and before November 17, 2006, when the installation passed its final inspection. At the time of the installation, the 2006 edition of NFPA 54: National Fuel Gas Code was the current industry standard.

The National Fuel Gas Code (NFPA 54), 2006 Edition prescribed recommended guidelines and requirements regarding gas distribution systems within buildings, including residential structures. This document's scope covers all the piping/tubing downstream from the gas meter (in natural gas installations) including "design, materials, components, fabrication, assembly, installation, testing, inspection, operation, and maintenance" of piping systems.[15]

The National Fuel Gas Code outlines its requirements for bonding in section 7.13.1:

> *Each aboveground portion of a gas piping system that is likely to become energized shall be electrically continuous and bonded to an effective ground-fault current path. Gas piping shall be considered to be bonded when it is connected to appliances that are connected to the appliance grounding conductor of the circuit supplying that appliance.*

The phrase "that is likely to become energized" was first inserted into the code in 2002. Per the National Fuel Gas Code Handbook (2006 edition), this requirement is designed to protect against the typical way gas piping becomes energized: by electrical energy from a connected appliance energizing the fuel gas piping. The handbook goes further to state that "If there are no appliances with electrical components connected to the piping system, then the gas piping system is not likely to become energized."[16] Based upon this statement, it is clear that the intention of the code requirement outlined in section 7.13.1 is designed to protect against stray household currents, and was not intended to be used to protect against lightning, or its effects.

Additionally, the handbook continues by stating that gas piping does require a separate bonding connection in the event that "there are sources of electricity outside the piping system that could energize the gas piping system. This situation is highly unlikely." Clearly, the members of the National Fuel Gas Code Committee, as well as the voting members of NFPA felt that lightning energy impacting a gas system was "highly unlikely" as they provided no guidance on bonding for lightning purposes.

Two new requirements specifically addressing the uniqueness of CSST were introduced in the 2006 edition of the National Fuel Gas Code.

Section 5.6.3.4 reads:

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[15] NFPA 54 2006 1.1.1.1(C)

[16] Lemoff, T. National Fuel Gas Code Handbook, 2006. National Fire Protection Agency. Page 135.

> ***Corrugated Stainless Steel.*** *Corrugated stainless steel tubing shall be listed in accordance with ANSI LC 1/CSA 6.26, Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing.*

The introduction of Section 5.6.3.4 required that CSST products be "Listed", or approved, by "an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose."[17] This code section made CSST the first and only allowable gas piping system that was "Listed" (tested and approved) prior to being installed. This meant that CSST was the first, and only, complete gas piping system that had been tested and found suitable for distribution of fuel gas within a building. TracPipe is listed in accordance with ANSI LC-1/CSA 6.26.

Section 7.2.8 reads:

> ***CSST.*** *CSST piping systems shall be installed in accordance with this code and the manufacturer's installation instructions.*

This code requirement clearly states that CSST products should be installed in accordance with the manufacturer's installation instructions in addition to requirements outlined in the National Fuel Gas Code. Omega Flex's installation instructions can be found in the TracPipe Flexible Gas Tubing Design Guide and Installation Instructions.

Design Guide and Installation Instructions

Omega Flex provides a document called the TracPipe Flexible Gas Piping Design Guide and Installation Instructions (D&I Guide) to their installers, and made up-to-date versions of this document available online as well as at every store at which TracPipe can be purchased. Omega Flex updated its D&I Guide multiple times to address new technology and code changes. The most recent edition of the D&I Guide at the time of this installation was the December 2005 version. That document provides detailed information regarding the uses, restrictions, and installation of TracPipe.

At the front of the guide, Omega Flex provides a page entitled "Warnings". On this page, the document states "The installation instructions and procedures contained in this Design Guide must be strictly followed in order to provide a safe and effective fuel gas piping system or system modification."[18] Additionally, on this page a highlighted box further warns that: "If this system is used or installed improperly, fire, explosion, or asphyxiation may result. The installation instructions and applicable local codes must be strictly followed."

The D&I Guide provides a specific section of the document entitled "Electrical Bonding/Grounding" which provides specific instructions for bonding the system. This section

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[17] NFPA 54. 2006. 3.2.4

[18] TracPipe Flexible Gas Tubing Design Guide and Installation Instructions, December 2005, Page 3.

of the guide states: "In accordance with The National Fuel Gas Code NFPA 54/ANSI Z223, each above ground portion of the gas piping system upstream from the equipment shutoff valve shall be electrically continuous and bonded to any grounded electrode, as defined by the *National Electric Code*, ANSI/NFPA 70 1999 Edition".[19] The guide continues by describing exactly how to bond the TracPipe system by using a bonding clamp that is attached to a brass Autoflare fitting (TracPipe connector) or to a black pipe component connected to that fitting.

Although the D&I guide borrows language from the 1999 edition of NFPA 54, it does not instruct the installer only to follow the requirements of NFPA 54 but rather explicitly states that bonding of the gas piping system to a grounding electrode is also required and describes how to perform that bonding. Furthermore, if an installer has any questions on bonding or any other installation requirements, the installer should not put the gas system into service, but rather should contact the manufacturer to understand the proper bonding requirements.

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[19] TracPipe Flexible Gas Tubing Design Guide and Installation Instructions, December 2005, Page 60. Note that the quoted text in the D&I Guide is from the 1999 edition of NFPA 54.

TracPipe Testing Performed by Exponent

Exponent has performed testing of TracPipe in order to determine whether electrical arcing with household branch circuit wiring can produce holes in TracPipe during a fire. Exponent also tested the ignitability of natural gas leaking from a perforation in TracPipe.

TracPipe and household electrical systems

TracPipe is surrounded by a yellow plastic insulating jacket. Household branch circuit wiring is also insulated. However, household voltage can cause arcing between TracPipe and electrical wiring in the presence of a fire, after the insulation has been compromised. Exponent has performed testing to demonstrate this mechanism.

A 14 AWG branch circuit cable (type NM-B) was connected in series to a 15 amp circuit breaker which was supplied by a 120 VAC electrical outlet protected by a 20 amp breaker. The live (or hot) conductor was separated from the neutral and ground conductors and placed near a length of TracPipe that was connected to a grounded water pipe using a stainless steel hose clamp. The insulating jacket on both the TracPipe and the live conductor was kept intact. A propane diffusion flame was then applied under the TracPipe and live conductor. A photograph of a sample a test is shown in Figure 5.

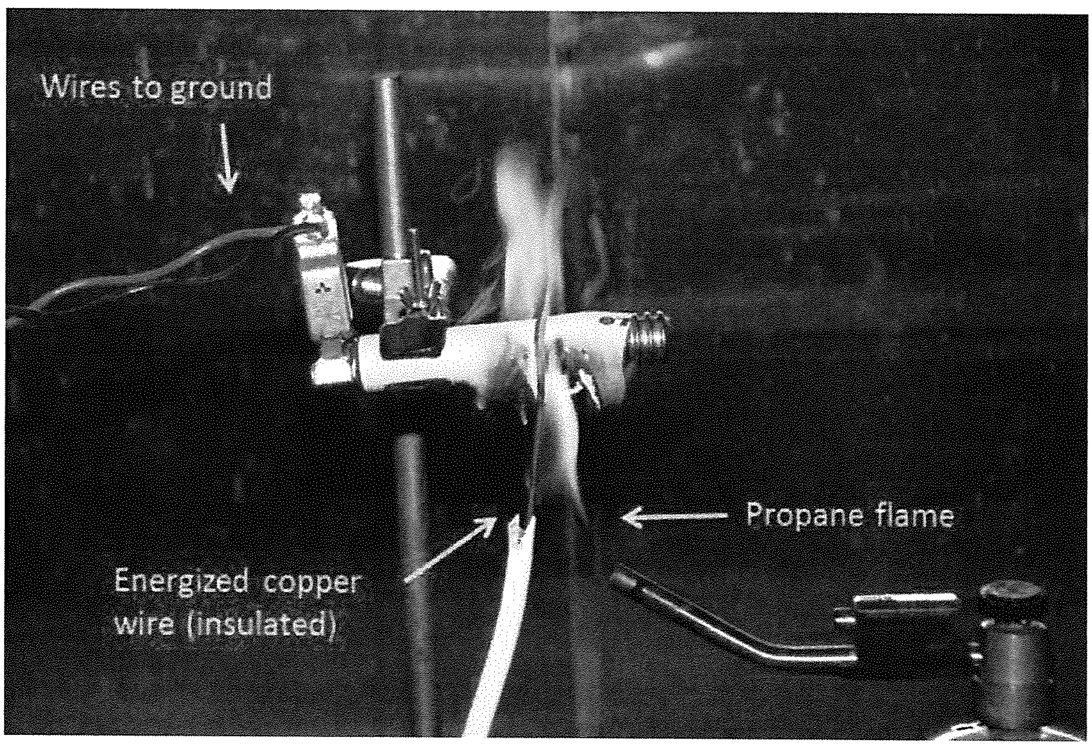

Figure 5. Photograph of the testing of TracPipe in proximity with energized branch circuit wiring in the presence of a flame.

Once the insulation on the conductor and the TracPipe began to burn away, an electrical arc occurred between the conductor and the TracPipe, forming a hole in the TracPipe. An optical microscope image of a hole from such a test is shown in Figure 6. This testing demonstrated that energized electrical wires can cause a hole in TracPipe in the presence of a pre-existing fire. It also allowed Exponent to examine the metallurgical characteristics of such holes. The character of the hole is similar to holes in TracPipe that were allegedly caused by an electrical arc due to lightning. Due to this similarity, it is not possible to identify the source of electrical energy that caused the hole (lightning or household electricity) from an examination of the hole alone.

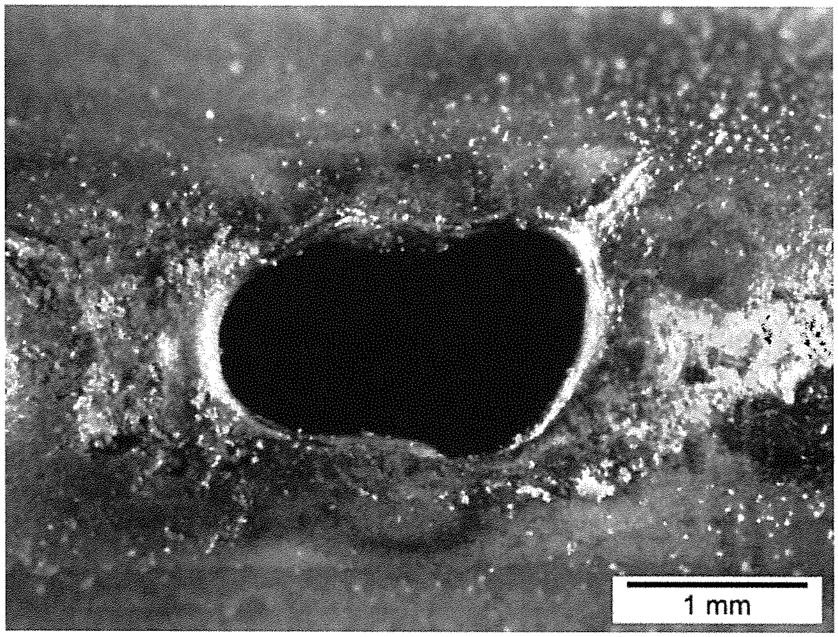

Figure 6. Optical microscope image of hole formed in TracPipe by household electricity in a flame.

Ignition of gas escaping from perforated TracPipe

In his report, Dr. Eagar has proposed that the natural gas that is released through a melted hole in CSST is then ignited by the molten steel.[20] Dr. Eagar provides no support for this opinion in his report. Mr. McLauchlan states in his report that the leaking gas is "typically ignited by residual heat from the arcing event". As evidence, Mr. McLauchlan points out that the melting point of steel is 2642 °F, which he states is above the autoignition temperature of natural gas. However, it is not enough simply to compare temperatures. It is well recognized in the scientific literature that the hot surface ignition temperature is usually significantly higher than the autoignition temperature. The ability of a hot surface to ignite flowing natural gas depends on many factors, such as velocity of the flowing gas and size of the hot surface.[21] A smaller surface area requires higher surface temperature to cause ignition, and a higher velocity of flowing gas

[20] December 12, 2011 report by Dr. Eagar, page 3, paragraph 3

[21] Laurendeau, N.M. Thermal Ignition of Methane-Air Mixtures by Hot Surfaces: A Critical Examination. *Combustion and Flame* 46:29-49 (1982).

requires a higher surface temperature to cause ignition. A scientific quantification of the temperature of a hot surface that is necessary to cause ignition of natural gas would require performing either additional testing or a detailed convective heat transfer analysis. Such testing or analysis would need to test the viability of the geometry and temperature distribution of an arc hole in CSST and its associated spatter as ignition sources. None of this has been performed by Dr. Eagar or by Mr. McLauchlan.

Furthermore, even if it was determined that the molten steel was sufficiently hot to ignite natural gas in general, the natural gas emanating from a hole in CSST could not be ignited by the molten steel at the hole because the gas has not mixed with air and the gas jet velocity is too high for combustion to be sustained. Diffusion flames require relatively low jet velocities in order to be sustainable.

Exponent has performed testing where a butane flame was placed at a hole in TracPipe that was connected to a natural gas supply at a pressure of 7 inches w.c. During such testing, Exponent was unable to ignite the gas. In order to demonstrate that a butane flame was a competent ignition source for natural gas, the flame was then moved a significant distance away from the tubing and the gas was then temporarily ignited. A flame could not be sustained once the butane flame was removed due to blow-off. Photographs from this testing are shown below in Figure 7 and Figure 8. The results of this testing demonstrate that a secondary ignition source, such as nearby burning combustibles, is required in order to ignite gas escaping from TracPipe holes.

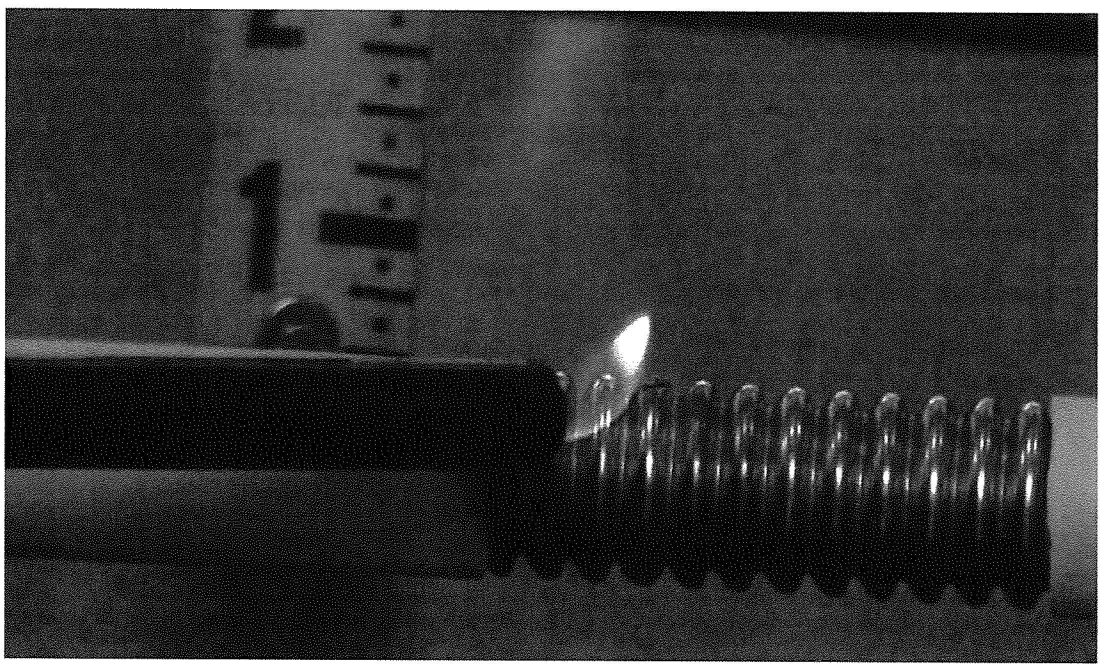

Figure 7. Photograph of ignition testing with natural gas and ½" TracPipe. Leaking natural gas could not be ignited at the hole.

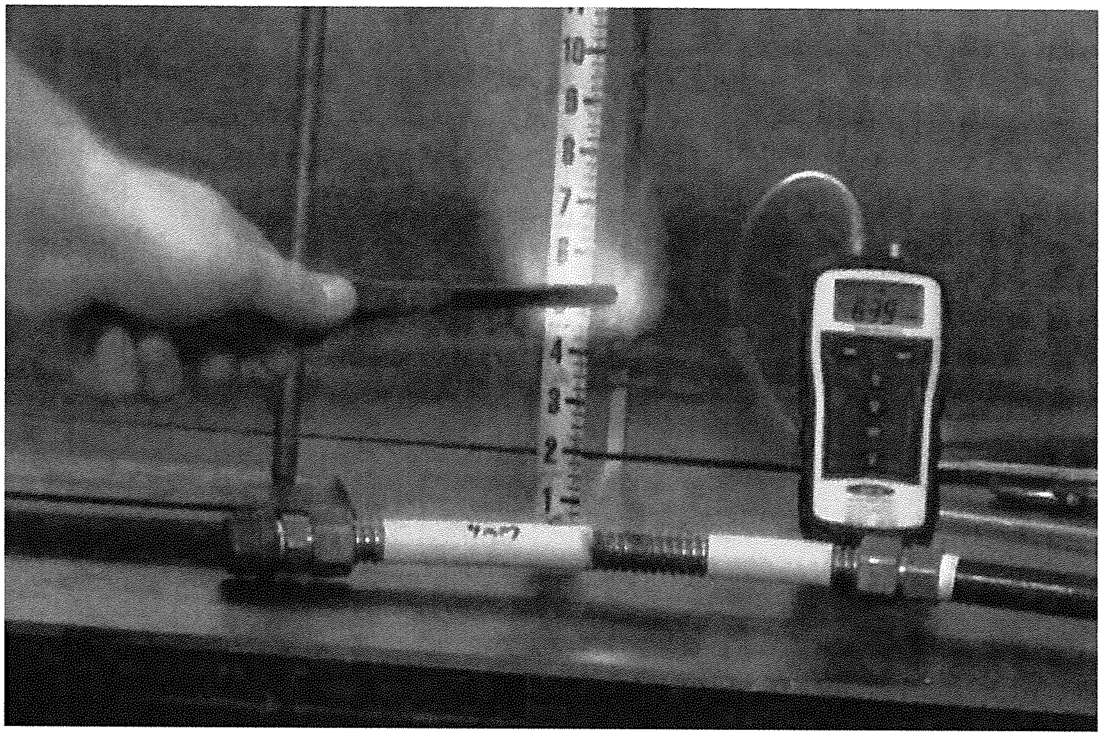

Figure 8. Photograph of ignition testing with natural gas and ½" TracPipe. Ignition of natural gas was possible only some distance away from the hole for a brief duration, but could not be sustained.

Analysis of the TracPipe holes

Two holes in the TracPipe at the Shamsher residence were identified: one in the line to the oven, and one in the supply line. The hole in the TracPipe line to the oven was found in the vicinity of the family room fire. The hole in the supply TracPipe line was found in the vicinity of the bedroom fire.

A microscopic inspection of the holes revealed that both holes were likely caused by electrical arcing. The electrical arc locally heated the stainless steel above its melting point causing a hole to form.

In his report, Dr. Eagar states that "the well-defined edges of the hole without the presence of a band of melted metal developing a rounded edge due to surface tension is only consistent with a very short duration arc such as produced by lightning."[22] However, from optical microscope images of the hole in the oven TracPipe line (shown in Figure 9), the hole clearly does have a band of melted metal with a rounded edge. It also looks similar to a hole produced by Exponent using household electricity during testing of TracPipe (see Figure 10). SEM images of the two holes are shown in Figure 11 and Figure 12. The microscopic images of the hole do not allow the determination of the source of electrical arcing that caused the hole. It could have been caused by arcing from an energized branch circuit wire or by arcing induced by lightning.

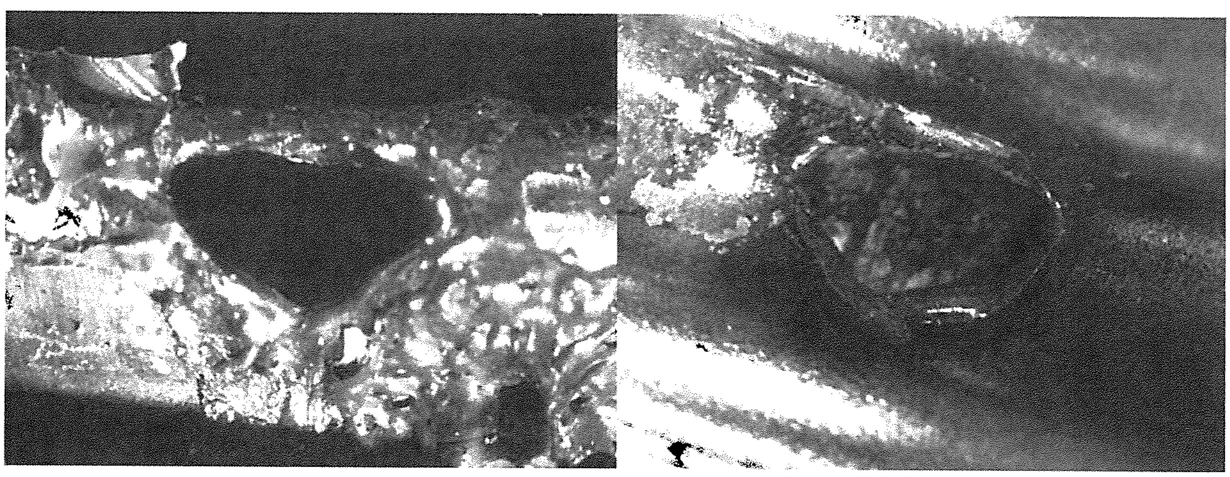

Figure 9. Optical microscope images taken at MIT of the hole in the oven TracPipe line (family room fire) at the Shamsher residence. The left image shows the outside of the TracPipe, the right image shows the inside.

[22] December 12, 2012 report by Dr. Eagar, page 7, paragraph 9.

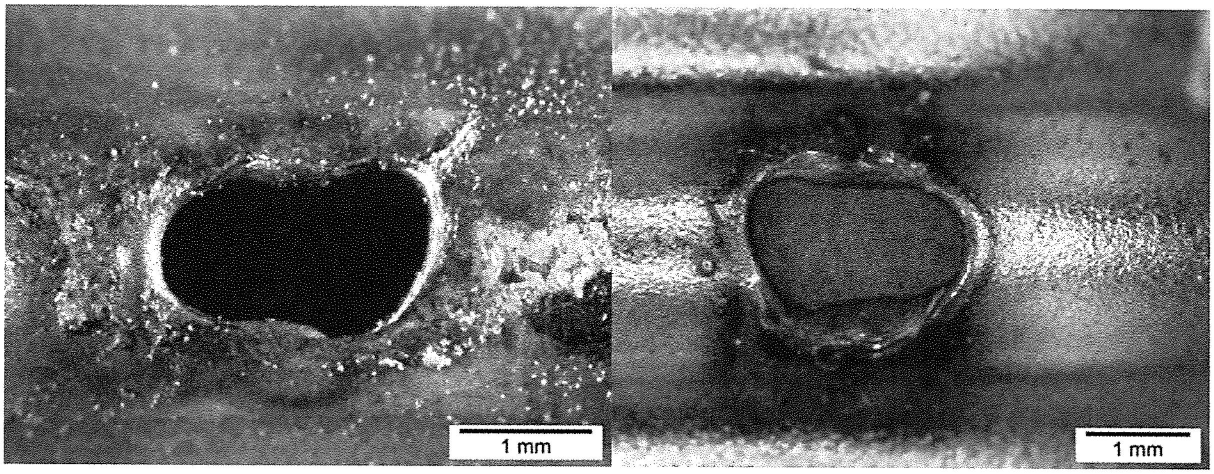

Figure 10. Optical microscope images taken by Exponent of a hole in TracPipe created by arcing with an energized branch circuit wire in the presence of a fire. The left image shows the outside of the TracPipe, the right image shows the inside.

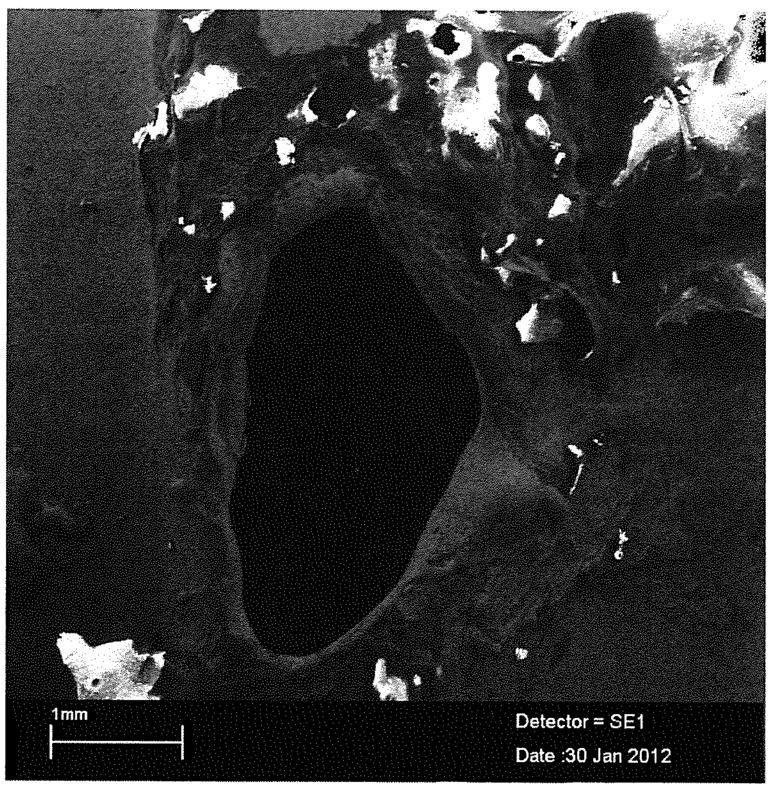

Figure 11. SEM images taken at MIT of the hole in the oven TracPipe line (family room fire) at the Shamsher residence. This image clearly shows the presence of a band of melted metal developing a rounded edge due to surface tension.

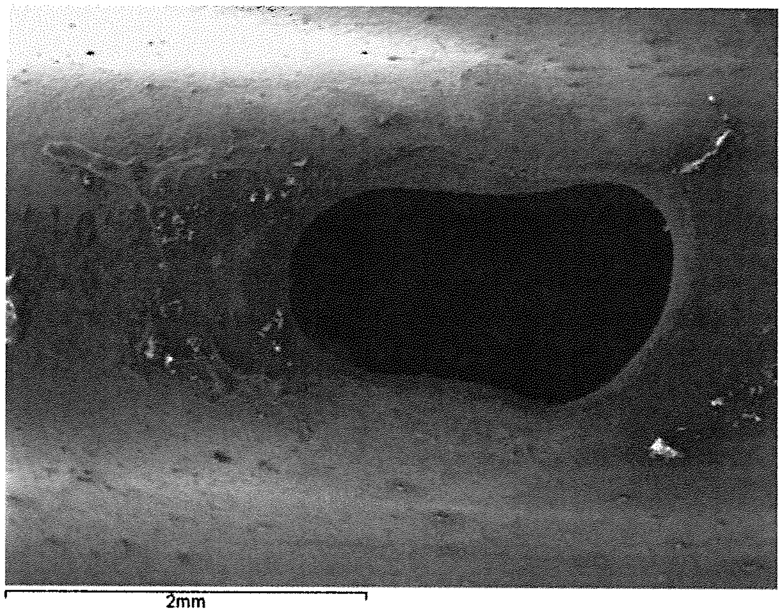

Figure 12. SEM images taken by Exponent of a hole in TracPipe created by arcing with an energized branch circuit wire in the presence of a fire. This is the same hole as shown in Figure 10. This image clearly shows the presence of a band of melted metal developing a rounded edge due to surface tension.

Origin and Cause Analysis

Two independent fires occurred at the Shamsher residence. One was above the basement family room in the space between the family room ceiling and the subfloor above (the family room fire). The other was a small fire above the basement spare bedroom also between the ceiling and subfloor above (the bedroom fire).

Family room fire

There were several electrical conductors in the area of burn damage in the family room, as well as a length of TracPipe (servicing the oven) and metal ducts. Evidence of arcing was found on sections of branch circuit wiring removed from the area of the fire. A hole was also found in the TracPipe in the general vicinity of the fire, with melted and resolidified metal around the hole, indicating that there was an electrical arc. The arc most likely jumped between the electrical conductors and the TracPipe. Note that the circuit breakers had all been switched off at the time of the initial inspection, so there is no information available regarding which, if any, circuit breakers tripped before or during the fire.

Natural gas leaking from a hole in TracPipe cannot be ignited at the hole as was demonstrated by testing described earlier in this report. Photographs of the area of fire damage show that there is relatively little damage to the I-joist immediately above the hole (indicated in Figure 13). The majority of the fire damage is to the I-joist to the right (west) of the hole, and the subfloor between the I-joist above the hole and the I-joist to the right of the hole (shown in Figure 13 and Figure 14). The natural gas was ignited by an existing fire, at least several inches from the hole, in the space between the I-joist above the hole, and the I-joist to the right.

The first fuel ignited was combustible materials in the space above the drywall ceiling in the basement and below the subfloor of the first floor. Combustible materials in that vicinity include, but are not limited to, dust, wood particles from wooden construction materials, insulation that ran between the wooden studs in front of the concrete wall, insulation above the concrete wall, and paper on the drywall boards on the ceiling or on the insulation.

The only ignition source that could have ignited these combustible materials was an electrical arc caused by lightning. After an initial arc to an energized branch circuit wire, there would have been additional follow-on current. The electrical event that ignited the combustible materials may have also melted a hole in the oven TracPipe line. However, it is also possible that the hole in the TracPipe was formed after the fire started, by an energized branch circuit wire, and that the lightning induced arc that was responsible for igniting the nearby combustible materials did not involve the TracPipe.

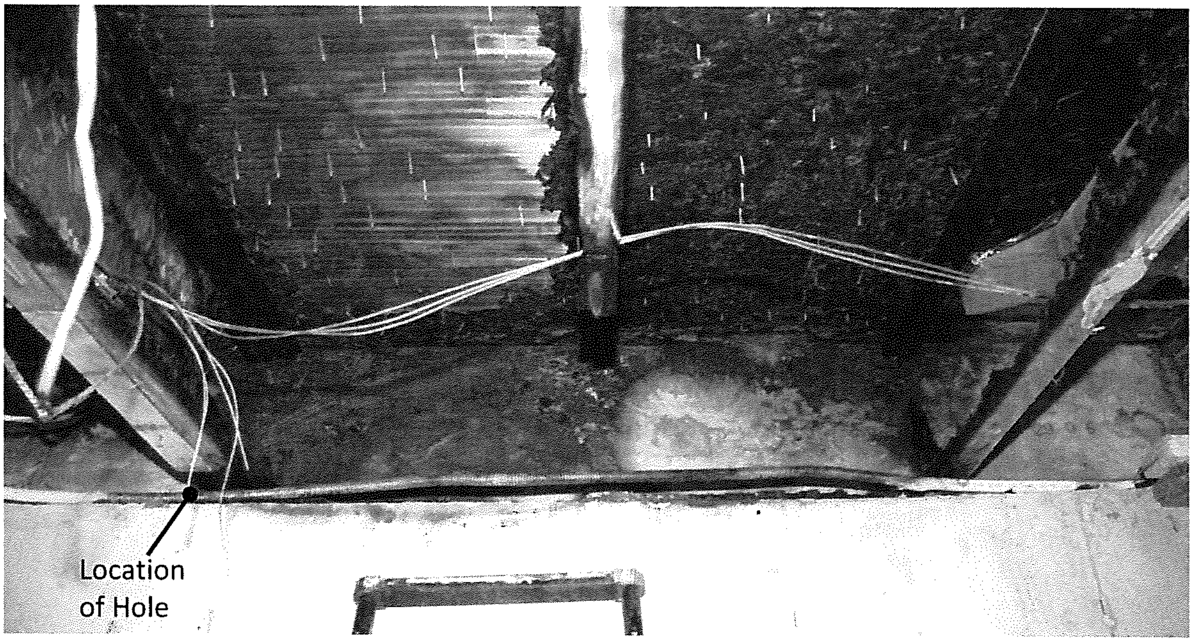

Figure 13. Photograph of the area of the family room fire.[23] The oven line TracPipe is visible running across the center of the photograph. The location of the hole found in the TracPipe is labeled.

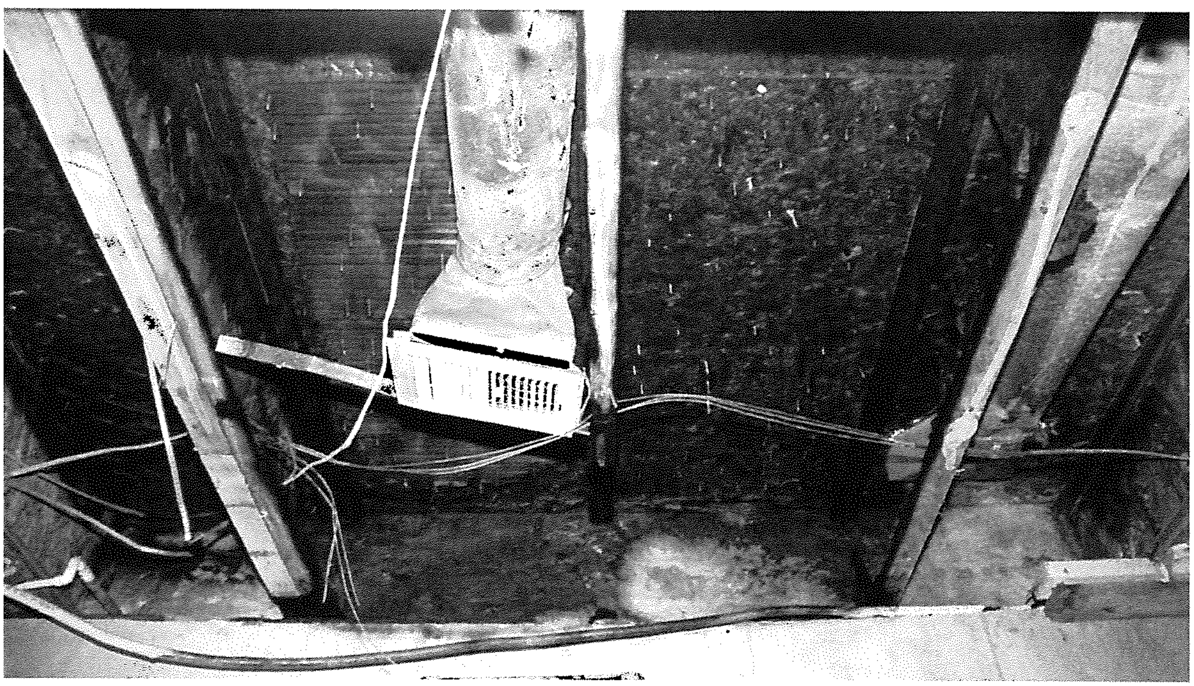

Figure 14. Photograph of the area of the family room fire, with the metal duct visible in the center of the photograph put back into its approximate location before the fire.[24]

[23] From set of photographs taken by Mr. Redsicker on July 27, 2009.

Bedroom fire

The bedroom fire caused only minimal damage, as shown in Figure 15. A hole was found in the supply TracPipe line in the vicinity of the fire, with evidence of melted metal around the hole, indicating that there was an electrical arc. There were no electrical wires in the vicinity of the hole. The arc most likely occurred between the TracPipe and the metal duct visible in Figure 15. Natural gas leaking from TracPipe cannot be ignited at the hole. Therefore, the first fuel ignited in the bedroom fire was likely dust or wood particles. This small fire then ignited the escaping natural gas some distance from the hole. There was no evidence of ignition sources other than electrical arcing. Therefore, the ignition source was an electrical arc due to lightning. Given the very small amount of damage, it is likely that the leaking gas was only burning for a short time, either because it self-extinguished soon after being ignited, or because it was not ignited until significantly after the initial fire was ignited by the arc.

Figure 15. Photograph of the damage caused by the bedroom fire.[25] A metal duct runs across the photograph. Two TracPipe lines run along the duct: the supply line closer to the duct, and the fireplace line farther from the duct. Thermostat wires also run along the duct.

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[24] From set of photographs taken by Mr. Redsicker on July 27, 2009.

[25] From set of photographs taken by Mr. Smith on August 27, 2009.

Indirect lightning strike

Both Mr. Redsicker and Mr. Smith state in their reports that there were no signs of direct lightning strike damage to the residence.[26] Photographs of the roof and roof penetrations do not show signs of a direct lightning strike. Therefore electrical energy entered the residence through an indirect lightning strike.

Grounding and bonding

The TracPipe system in the Shamsher residence was not directly bonded to the grounding electrode as required by the D&I guide. Mr. Redsicker noted in his report that the TracPipe was connected to ground through several appliances. He also states that there was an electrical connection between the TracPipe and the water piping system as determined using a multimeter.[27] Mr. Rediscker does not report the impedance of the electrical connection, but it was most likely made through a long and relatively high impedance path: the TracPipe was connected to an appliance; the appliance was connected to a grounded branch circuit wire, which was connected to the electrical panel, which was connected to the water system. The impedance through this path is not sufficiently low to prevent a high electric potential difference and arcing between two adjacent conductors in the event of a lightning strike. Mr. Goodson agrees on this point, in his report he states: "the EGC [equipment grounding conductor] is inadequate for dealing with lightning type currents."[28] Per the manufacturer's instructions, the TracPipe must be directly bonded to the electrical ground to protect against indirect lightning strikes.

[26] December 9, 2011 report by Mr. Redsicker, page 3. September 25, 2009 report by Mr. Smith.

[27] December 9, 2011 report by Mr. Redsicker, page 16.

[28] December 12, 2011 report by Mr. Goodson, page 4.

Limitations

At the request of Campbell Campbell Edwards & Conroy, P.C., Exponent conducted an investigation of the fire that occurred at the Shamsher residence on July 23, 2009 for the purposes of an ongoing legal matter. Exponent investigated specific issues relevant to this incident as requested by Campbell Campbell Edwards & Conroy, P.C. The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

The findings presented herein are made to a reasonable degree of engineering certainty. We have made every effort to accurately and completely investigate all areas of concern identified during our investigation. If new data becomes available or there are perceived omissions or misstatements in this report regarding any aspect of those conditions, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them.

Appendix A – Material Reviewed

1. Shamsher Dwelling Fire Investigation Preliminary Report by Aaron Redisker, Scientific Expert Analysis. December 9, 2011.
2. Report by Mark Goodson, Goodson Engineering Consulting Services. December 12, 2011.
3. Report by Ken McLauchlan, McLauchlan & Associates Inc. December 15, 2011.
4. Report by Tom Eagar, Materials and Engineering Group, LLC. December 12, 2011.
5. Report of Fire Analysis by David Smith, Smith and Associates. September 25, 2009.
6. Prince George's County Fire/EMS Department Incident Report. Incident number 2009-2040426.
7. Vaisala STRIKEnet report number 607723, July 23, 2009.
8. Kraft, B. and Torbin, R. *Effectiveness of Direct Bonding of Gas Piping in Mitigating Damage from an Indirect Lightning Strike*. 2007.
9. NFPA 54, 2006 edition.
10. National Electric Code, 2005 edition.
11. TracPipe Flexible Gas Tubing Design Guide and Installation Instructions. December 2005.
12. *Testing to Compare the Seismic Response of TracPipe Flexible Gas Piping (CSST) with Black Steel Piping Systems Under Simulated EarthQuake Induced Motions*. Report to Omega Flex. November 11, 1998.
13. Evarts, B. *Lightning Fires and Lightning Strike*. National Fire Protection Association, Fire Analysis and Research Division. December 2010.
14. Chowduri et.al. Parameters of Lightning Strokes: A Review. *IEEE Transactions on Power Delivery*. Vol 20, No. 1. January 2005.
15. Lemoff, T. *National Fuel Gas Code Handbook*. 2006. National Fire Protection Agency.
16. Laurendeau, N.M. Thermal Ignition of Methane-Air Mixtures by Hot Surfaces: A Critical Examination. *Combustion and Flame* 46:29-49 (1982).

Appendix B

Curriculum Vitae

Exponent®
Failure Analysis Associates®

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Timothy L. Morse, Ph.D., P.E., CFEI
Senior Engineer

Professional Profile

Dr. Timothy L. Morse is a Senior Engineer in Exponent's Thermal Sciences practice. Dr. Morse specializes in the engineering analysis and experimental testing of thermal and flow processes and equipment. His project experience has included turbines, compressors, boilers, heat transfer systems, flammable liquids, and cryogenic liquids. Dr. Morse has performed engineering analysis for the oil and gas industry, ranging from natural gas extraction facilities to retail motor fuel stations. He also has experience with offshore facilities. Dr. Morse has performed analysis on wind farms and investigated failures in wind turbines. He has also applied his expertise to intellectual property matters involving thermal or flow processes.

Dr. Morse also applies his expertise to the investigation and prevention of fires, explosions, and equipment failures. He has conducted fire origin and cause analysis involving electrical appliances, consumer products, boilers, and other combustion equipment. Dr. Morse has also investigated the origin and cause of fires in motor vehicles, including post-collision motor vehicle fires. Dr. Morse has experience in the testing and analysis of HVAC systems and components, including the analysis of the production and spread of carbon monoxide. He has significant experience with instrumentation and experimental measurement techniques in flow and thermal systems, including flow visualization and flow velocity measurement with laser diagnostic and acoustic diagnostic methods.

Prior to joining Exponent, Dr. Morse was a graduate researcher in the Fluid Dynamics Research Laboratories at Cornell University. He has conducted research on the wakes of stationary and oscillating structures in a flow and particularly on how flow-induced vibration due to vortex shedding causes fatigue and failure of structures. A significant component to this research was extensive measurements and analysis of the fluid forcing on a structure in a flow, combined with detailed measurements of the wake flow field using Digital Particle Image Velocimetry (DPIV).

Academic Credentials and Professional Honors

Ph. D., Mechanical Engineering, Cornell University, 2009
M.S., Mechanical Engineering, Cornell University, 2007
B.E., Mechanical Engineering, The Cooper Union (*summa cum laude*), 2003

National Science Foundation Fellowship, 2004–2008; National Defense Science and Engineering Graduate Fellowship, 2004–2007; Ralph Bolgiano, Sr. Outstanding Teaching Assistant Award, Cornell University, 2006; Cornell University Graduate Fellowship, 2003; Tau Beta Pi Fellowship, 2003; New York Association of Consulting Engineers Scholarship, 2002; Tau Beta Pi Engineering Honor Society, 2002; Pi Tau Sigma Mechanical Engineering Honor Society, 2002

Licenses and Registrations

Registered Professional Mechanical Engineer, California, #35464; Certified Fire and Explosion Investigator (CFEI) in accordance with the National Association of Fire Investigators; Hazardous Waste Operation and Emergency Response Certification, 29 CFR 1910.120

Publications

Morse TL, Kytömaa HK. The effect of turbulence on the rate of evaporation of LNG on water. Journal of Loss Prevention in the Process Industries 2011; 24:791–797.

Morse TL, Williamson CHK. Steady, unsteady, and transient vortex-induced vibration predicted using controlled motion data. Journal of Fluid Mechanics 2010; 649:429–451.

Morse TL, Williamson CHK. Prediction of vortex-induced vibration response by employing controlled motion. Journal of Fluid Mechanics 2009; 634:5–39.

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Morse TL. Investigating phenomena in vortex-induced vibration of a cylinder using controlled vibration. Ph.D. Thesis, Cornell University, 2008.

Morse TL, Govardhan RN, Williamson CHK. The effect of end conditions on the vortex-induced vibration of cylinders. Journal of Fluids and Structures 2008; 24:1227–1239.

Morse TL, Williamson CHK. Understanding mode transitions in vortex-induced vibration using controlled motion. Proceedings, 9th International Conference on Flow-Induced Vibrations (FIV-2008), Prague, Czech Republic, 2008.

Kysar JW, Gan YX, Morse TL, Chen X, Jones ME. High strain gradient plasticity associated with wedge indentation into face-centered cubic single crystals: Geometrically-necessary dislocation densities. Journal of the Mechanics and Physics of Solids 2007; 55(7):1554-1573.

Morse TL, Williamson CHK. Understanding mode transitions in vortex-induced vibration using controlled vibration. Proceedings, 5th Conference on Bluff Body Wakes and Vortex-Induced Vibration (BBVIV-5), Costa do Sauipe, Brazil, 2007.

Morse TL, Williamson CHK. Employing controlled vibrations to predict fluid forces on a cylinder undergoing vortex-induced vibration. Journal of Fluids and Structures 2006; 22:877–884.

Gan YX, Kysar JW, Morse TL. Cylindrical void in a rigid-ideally plastic single crystal II: Experiments and simulations. International Journal of Plasticity 2006; 22(1):39–72.

Morse TL, Williamson CHK. Employing controlled vibrations to predict fluid forces on a freely vibrating cylinder. Proceedings, 4th Conference on Bluff Body Wakes and Vortex-Induced Vibration (BBVIV-4), Santorini, Greece, 2005.

Presentations

Morse TL, Kytömaa HK. Variations in the evaporation rate of a cryogenic liquid on a water surface. Mary Kay O'Connor Process Safety Center 2010 International Symposium. College Station, TX, October 2010.

Morse TL, Kytömaa HK. The effect of turbulence on the evaporation of cryogenic liquid spills on water. AIChE Spring Meeting, 10th Topical Conference on Natural Gas Utilization, San Antonio, TX, March 2010.

Morse TL, Williamson CHK. Understanding mode transitions in vortex-induced vibration using controlled motion. 9th International Conference on Flow-Induced Vibrations (FIV-2008), Prague, Czech Republic, 2008.

Morse TL, Williamson CHK. Understanding mode transitions in vortex-induced vibration using controlled vibration. 5th Conference on Bluff Body Wakes and Vortex-Induced Vibration (BBVIV-5), Costa do Sauipe, Brazil, 2007.

Morse TL, Williamson CHK. Employing controlled vibrations to predict fluid forces on a freely vibrating cylinder. 4th Conference on Bluff Body Wakes and Vortex-Induced Vibration (BBVIV-4), Santorini, Greece, 2005.

Morse TL, Williamson CHK. An investigation of wake mode transitions and amplitude jumps in vortex-induced vibration using controlled vibration. 60th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Salt Lake City, UT, 2007.

Morse TL, Williamson CHK. Understanding mode transitions in vortex-induced vibrations of a circular cylinders using controlled vibration. 59th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Tampa, FL, 2006.

Morse TL, Williamson CHK. Predicting the response of a cylinder undergoing vortex-induced vibration using controlled vibrations. 58th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Chicago, IL, 2005.

Morse TL, Williamson CHK. Forces on a cylinder with periodic transverse motion in a free stream. 57th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics, Seattle, WA, 2004.

Peer Reviewer

- *Journal of Fluids and Structures*
- *Journal of Wind Engineering*
- *International Journal of Heat and Fluid Flow*

Professional Affiliations

- American Society of Mechanical Engineers
- National Fire Protection Association
- National Association of Fire Investigators